EFFECT OF THE DOUBLE-BOUNCE CONTRIBUTION IN POLINSAR-BASED HEIGHT ESTIMATES OF RICE CROPS USING TANDEM-X BISTATIC DATA

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ABSTRACT

In bistatic acquisitions the presence of a double-bounce contribution at the ground affects the interferometric coherence with a decorrelation factor which is usually overlooked in studies employing polarimetric SAR interferometry. The standard acquisition mode of TanDEM-X is bistatic, so the influence of this contribution in the estimation of scene parameters (ground topography and vegetation height) is studied here. The analysis is carried out both with simulations and real data acquired over rice fields during the science phase of TanDEM-X. Results show that the error in height and topography is small when incidence angle is below 30 degrees, but may become noticeable for shallower incidences.

Index Terms— Polarimetric SAR interferometry, vegetation, TanDEM-X, bistatic radar, rice

1. INTRODUCTION

The estimation of biophysical variables of scenes with vegetation (forest and agriculture) by means of polarimetric SAR interferometry (PolInSAR) [1] is based on the inversion of a physical model of the scene that relates the biophysical variables (topography, vegetation height, extinction, etc.) and the observables available in PolInSAR, i.e. complex interferometric coherences at different polarimetric channels. The most widely used model for this purpose is the random volume over ground (RVoG), originally formulated in [2, 3, 4].

Before the launch of TanDEM-X, all PolInSAR data employed in studies over vegetation were gathered in repeat-pass mode, i.e. sets of polarimetric images were acquired over the scene at different times by a radar operating in monostatic mode. However, the standard acquisition mode of TanDEM-X is single-pass as a result of its bistatic configuration (one satellite transmits and both of them receive, i.e. there is one monostatic image and one bistatic image). In the derivation of the expression of the interferometric coherence of the RVoG model there are two main differences between both acquisition modes. The first difference is well-known in SAR interferometry and consists in the scaling of the wavenumber with the path difference: there is a 2 factor in repeat-pass systems which is 1 in bistatic mode. The second difference is specific of this model and corresponds to an extra decorrelation term that affects the double-bounce contribution to the radar response coming from the ground. The double-bounce decorrelation term appeared in the original formulation of the RVoG model [2] and was analysed later in [5, 6] from the theoretical point of view. Until the launch of TanDEM-X, neither this formulation was proven with experimental data nor the RVoG model was employed with bistatic data.

In the last three years, several groups have reported successful results in forest height retrieval with PolInSAR by exploiting TanDEM-X data [7, 8, 9, 10], and in all of them the double-bounce decorrelation term was ignored. More recently, crop height of rice fields was estimated correctly with TanDEM-X data as input, but in this case the double-bounce decorrelation term was taken into account in the inversion of the RVoG model [11].

In this work we analyse the influence of the double-bounce decorrelation term on the inversion of ground topography and vegetation height. For this purpose, simulated data with and without that term are employed as input to inversion procedures which consider or not that aspect. The difference of the retrieved values with respect to the actual ones, as well as the differences between approaches, are evaluated, and the influence of system parameters (baseline and incidence angle) is assessed. Finally, experimental results over rice fields are used to estimate the influence of this aspect on a final application.

2. FORMULATION

The RVoG model considers the scene is formed by two layers: a vegetation volume and a ground surface. The scattering from the ground is located at a single point in the vertical coordinate z_0, whereas the scattering from the volume is distributed according to a scattering function $f(z)$. Starting from this assumption it is possible to express the coherences $\tilde{\gamma}$ that are obtained at different polarimetric channels $\vec{w}$ as a function of the scene properties and the vertical wavenumber κ_Z. The

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most complete expression for a bistatic system, considering that the response from the ground can be composed of two contributions (surface or direct scattering, and double-bounce scattering) is the following [2, 3, 5, 6, 7]:

$$\tilde{\gamma}(\kappa_Z, \vec{w}) = e^{i\phi_0} \frac{\tilde{\gamma}_V + m_D(\vec{w}) + \frac{\sin k_z h_v}{k_z h_v} m_{DB}(\vec{w})}{1 + m_D(\vec{w}) + m_{DB}(\vec{w})} \quad (1)$$

where $\phi_0 = \kappa_Z z_0$ is the interferometric phase corresponding to the ground surface; $m_D(\vec{w})$ and $m_{DB}(\vec{w})$ are the ground-to-volume backscatter ratios corresponding to the direct D and double-bounce DB contributions, respectively; and h_v is the vegetation height (i.e. the depth of the vegetation volume). The first term in the numerator, $\tilde{\gamma}_V$, is the coherence that would produce the volume alone (without the presence of the ground), which can be expressed as a function of $f(z)$ as:

$$\tilde{\gamma}_V = \frac{\int_0^{h_v} f(z) e^{i\kappa_Z z} dz}{\int_0^{h_v} f(z) dz}. \quad (2)$$

The $\sin(x)/x$ term that appears in (1) before the double-bounce ground-to-volume ratio in the numerator is a decorrelation term present whenever a bistatic configuration is used. The argument of this term is $k_z h_v$, not $\kappa_Z h_v$. Wavenumber k_z is defined as (see [3, 5, 6] for details):

$$k_z = \kappa_Z \sin^2 \theta_0. \quad (3)$$

Hereafter we will use γ_{DB} to refer to the decorrelation term due to the presence of the double-bounce contribution at the ground:

$$\gamma_{DB} = \frac{\sin k_z h_v}{k_z h_v} \quad (4)$$

In many natural scenes we can expect the ground contribution to be dominated by the direct response of the ground surface, so the coherence expression would be:

$$\tilde{\gamma}(\kappa_Z, \vec{w}) = e^{i\phi_0} \frac{\tilde{\gamma}_V + m_D(\vec{w})}{1 + m_D(\vec{w})} \quad (5)$$

In other scenarios, as in rice fields and mangroves, the flooded ground acts like a mirror. In such a case the double-bounce contribution dominates the ground contribution and the coherence expression results in:

$$\tilde{\gamma}(\kappa_Z, \vec{w}) = e^{i\phi_0} \frac{\tilde{\gamma}_V + \frac{\sin k_z h_v}{k_z h_v} m_{DB}(\vec{w})}{1 + m_{DB}(\vec{w})} \quad (6)$$

Whenever there is no clear dominance of one of the two ground contributions, (1) should be used [6].

The effect of the double-bounce decorrelation term is illustrated in Fig. 1. The true topographic phase ϕ_0 is defined by the crossing of the line with the circumference of radius γ_{DB}, which is different from the phase ϕ_0' that would have been obtained by the crossing with the unit circumference, i.e. when the direct ground contribution dominates (5). Hence, the first effect of the model selection is a bias in the estimation of ground topography. In second place, a wrong topography will influence the estimation of the rest of model parameters. These aspects are discussed in next section.

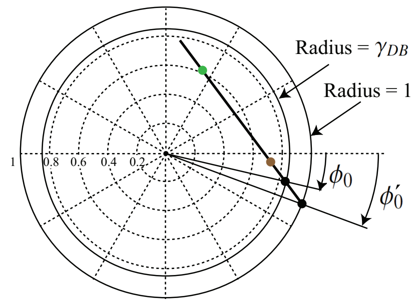

Fig. 1. Unit circle on the complex plane with the representation of the coherences and the line of the RVoG model when the double-bounce ground contribution dominates (6).

3. EVALUATION WITH SIMULATED DATA

In this paper we present results concerning agriculture applications, for which we consider system configuration parameters of TanDEM-X during its science phase, from April to September 2015. The most relevant feature is a large baseline, which is required to provide enough vertical sensitivity to work with short vegetation, i.e. crops.

3.1. Effect on the Topography Estimation

Topography is usually estimated before the rest of parameters using a line fit on the complex plane [4]. The first test corresponds to the error produced in the inversion of the topographic phase in the case illustrated in Fig. 1, i.e. when data correspond to a scene in which the double-bounce ground contribution is dominant (6) but the model used for the retrieval considers the ground dominated by the direct contribution (5). The phase error is defined as $\Delta\phi_0 = \phi_0 - \phi_0'$, and is translated into topography error as $\Delta z_0 = \Delta\phi_0 / \kappa_Z$.

Fig. 2 shows the topographic error Δz_0 obtained for a range of vegetation heights h_v and for four different incidence angles. In this example the height of ambiguity is either HoA = 3 m, which corresponds to a vertical wavenumber κ_Z = 2.1 rad/m, or HoA = 5 m, which corresponds to κ_Z = 1.25 rad/m. In general, the larger the vegetation height the larger the error, since γ_{DB} decreases with height, and the circumference which fixes the topographic phase shrinks. However, for steep incidence angles the error is negligible, e.g. less than 1 cm for 20 degrees and less than 3 cm for 30 degrees. This is a consequence of the conversion factor between κ_Z and k_z, explained in (3). When one moves to shallower incidence angles, like 40 or 50 degrees, the error is more noticeable. With HoA = 3 m the error reaches 7 cm and 15 cm, respectively, for vegetation

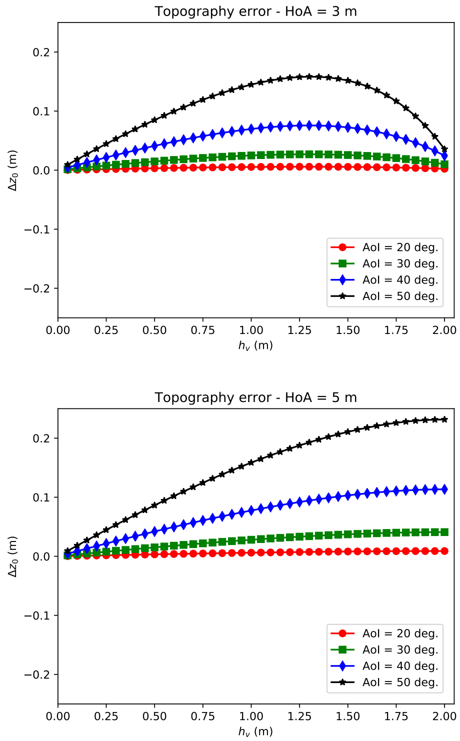

Fig. 2. Topographic error Δz_0 obtained as a function vegetation height h_v for four different incidence angles. Cases: Top) HoA = 3 m (κ_Z = 2.1 rad/m), and Bottom) HoA = 5 m (κ_Z = 1.25 rad/m)

heights around 1.2 m. With HoA = 5 m the maximum errors at 40 and 50 degrees correspond to the maximum height (2.0 m), with values of 11 and 23 cm, respectively. These values correspond to relative errors around 6 % and 13 %, respectively, which could be important depending on the final application.

3.2. Effect on the Vegetation Height Estimation

An error in the topographic phase estimation influences also the estimation of the rest of model parameters. In this section we show the error produced in the estimation of vegetation height, for which a large number of simulations are carried out with wide ranges of the model parameters. Before that, we have to clarify that the inversion of the RVoG model is expected to suffer problems even in the case of ideal data acquired in monostatic mode, due to lack of sensitivity for very short heights and other numerical limitations related to the numerical optimisation. Hence, it is important to separate the errors produced by the presence of the double-bounce term from the intrinsic errors that would appear also in its absence.

Fig. 3 compares the error produced in the estimation of vegetation height using the RVoG model in three cases: when both direct model and inversion correspond to equation (5), when the direct model corresponds to a dominant double-bounce contribution (6) but the inversion ignores it, i.e. it employs (5), and when both direct model and inversion correspond to equation (6). In the first two cases there is a significant overestimation of height when its actual value is below 20 cm, which is a limitation due to the baseline. For short vegetation, the product of height and vertical wavenumber is very small, which means that there is not enough interferometric sensitivity to the vertical distribution of scatterers in the scene. However, this overestimation becomes less noticeable when the inversion model takes into account the

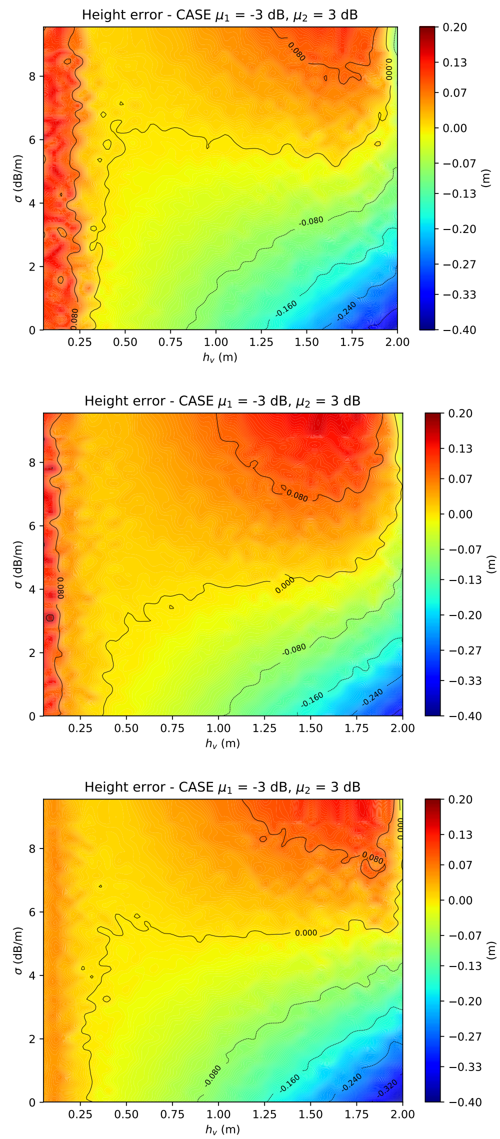

Fig. 3. Error in the vegetation height estimation for scenes with ranges of values of vegetation height (0.05 to 2.0 m) and extinction (0.1 to 10 dB/m). The ground-to-volume ratios of the two measured coherences are -3 dB and 3 dB. Other system parameters: HoA = 3 m, AoI = 30 degrees. Top) Direct model and inversion corresponding to equation (5). Middle) Direct model with double-bounce decorrelation, as in (6), but inversion of the model without it, i.e. (5). Bottom) Direct model and inversion with double-bounce decorrelation, corresponding to equation (6).

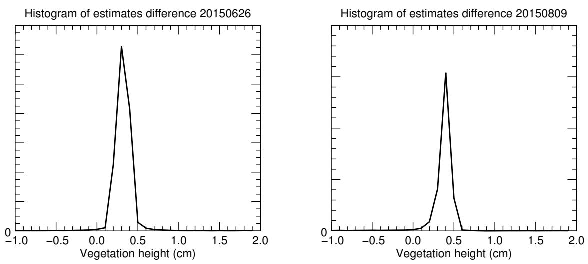

Fig. 4. Histogram of the difference between heights retrieved considering or not the double-bounce decorrelation term, over the monitored rice fields close to Sevilla. Dates: 26-Jun-2015 (top) and 09-Aug-2015 (bottom)

double-bounce contribution, as in the third case. A second behaviour common in the three cases is the error when height is above 1 m and extinction is either low or high, so the figures are quite similar in this zone. A more detailed comparison between the figures tells us that the overestimation for low heights is worse in the second case, i.e. when direct and inverse model do not match. For the rest of vegetation heights there exists a difference around 1–2 cm in the retrieved values, so the effect of the double-bounce is not really important.

4. EVALUATION WITH TANDEM-X DATA

In order to test the influence of the double-bounce decorrelation term on the final height estimates in a real scenario, the retrieval of height estimates carried out in [11] over the Sevilla test site was repeated here but without considering that term, i.e. using directly equation (5) in the inversion. The histograms of the difference between height estimates obtained with the methodology described in [11] and with the simplified method are shown in Fig. 4 for two different dates. Vertical wavenumber is 2.48 rad/m (HoA = 2.53 m) and incidence angle is 22.7 degrees. Results demonstrate that the bias caused by ignoring the double-bounce decorrelation is negligible (below 0.5 cm) for this test case.

5. CONCLUSIONS

The inclusion of the double-bounce decorrelation term complicates the inversion of the RVoG model when estimating ground topography and vegetation height. That inclusion, despite being more rigorous, is not necessary in many occasions because the retrieved values are not very different from the actual ones. The error only becomes noticeable for incidence angle shallower than 30 degrees and large products of vertical wavenumber and vegetation height.

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